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# Use of Sediment Trend Analysis (STA®) for Coastal Projects

*by Steven A. Hughes*

**PURPOSE:** The Coastal and Hydraulics Engineering Technical Note (CHETN) described herein provides information about the use of Sediment Trend Analysis (STA®)<sup>1</sup> for estimating net sediment pathways in coastal and estuarine environments. The STA technique is based on analyses of sediment samples collected over a uniform grid in the region of interest, and it provides maps indicating sediment pathways, erosion and accretion areas, and areas that are in dynamic equilibrium.

**PRINCIPLES BEHIND SEDIMENT TREND ANALYSIS:** The theory behind Sediment Trend Analysis was first published by McLaren and Bowles (1985). In simplest terms the STA method uses differences in grain-size distributions from bottom sediment samples collected on a regular grid to infer net sediment pathways and regions of erosion, accretion, and dynamic equilibrium. Specifically, sediment samples are collected in the area of interest from the top 10–15 cm of the bottom sediment. The sample grain-size distributions are determined primarily using a laser-based particle-size analyzer. Coarse sediment particles in the size range from 0.7 mm through 4.0 mm in diameter are mechanically sieved, and the results are merged with the majority of the distribution determined by the particle-size analyzer. The STA technique uses the first three central moments from the grain-size distribution: mean, variance (or sorting), and skewness. Other sediment properties such as mineralogy, texture, and shape are not considered in the analysis.

The basic assumption inherent in STA is that differences in sediment grain-size distributions can be due to sediment transport. In other words, the grain-size distribution may change as sediment moves along a pathway, and every deposit is a result of the processes responsible for sediment movement. This implies active periods of sediment transport occurring at the site at least part of the time.

McLaren and Bowles (1985) identified three possibilities that can be characterized by relative differences in grain-size distribution parameters between two locations, designated as distributions  $d_1$  and  $d_2$ .

**Case A: Lag deposit.** If distribution  $d_2$  has a coarser mean, is better sorted (smaller variance or standard deviation), and more positively skewed than distribution  $d_1$ , then sample  $d_2$  is a lag deposit of sample  $d_1$ , and both distributions were originally the same. In this case no direction of transport can be determined.

**Case B: Fining Sediments.** If distribution  $d_2$  has a finer mean, is better sorted (smaller variance or standard deviation), and more negatively skewed than distribution  $d_1$ , then the transport direction is from sample  $d_1$  to sample  $d_2$ . In this case the energy regime transporting

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<sup>1</sup> This CHETN attempts to provide a balanced description of the Sediment Trend Analysis technique and how it may be beneficial to coastal projects. This technical note should not be considered an official Corps of Engineers endorsement or recommendation of the Sediment Trend Analysis technique or of the private company GeoSea Consulting, Ltd., that performs STA studies.

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the sediment is decreasing from  $d_1$  to  $d_2$ , and the coarser grains are not transported as far as the finer grains before depositing.

**Case C: Coarsening Sediments.** If distribution  $d_2$  has a coarser mean, is better sorted, and more positively skewed than distribution  $d_1$ , then the transport direction is from sample  $d_1$  to sample  $d_2$ . In this case, the energy regime is also decreasing from  $d_1$  to  $d_2$ . Initially, this case is counterintuitive because coarse grains are not expected to be transported while finer grains are left behind. A plausible physical explanation is that “armoring” has occurred at location  $d_1$ , effectively trapping the underlying layers of finer material. Thus, the  $d_1$  distribution obtained as a grab sample contains a larger percentage of fine-grained particles that were shielded by the overlying layer of coarser grains. The energy level is such that coarse particles can be transported until they are deposited at site  $d_2$  as the energy level decreases. Finer-grained sediment will continue to be transported past the  $d_2$  location.

Only Cases B and C can be used to infer direction of sediment transport. The other six possible combinations of relative differences in grain-size distribution mean, sorting, and skewness cannot be used to determine a transport direction. Distinguishing between Cases A and C depends on further interpretation of the differences between the energy transfer functions that are constructed based on theoretical considerations. See McLaren and Bowles (1985) for theory details. Table 1 summarizes the three pertinent cases.

<b>Table 1</b>		
<b>Sediment Transport Trend Based on Grain-Size Distribution</b>		
<b>Case</b>	<b>Relative Change in Parameter from Deposit <math>d_1</math> to Deposit <math>d_2</math></b>	<b>Interpretation</b>
A	Coarser Better sorted More positively skewed	Deposit $d_2$ is a lag deposit of $d_1$ . No direction of transport can be determined.
B	Finer Better sorted More negatively skewed	Transport direction is from $d_1$ to $d_2$ . Energy regime is decreasing. Low energy transfer functions.
C	Coarser Better sorted More positively skewed	Transport direction is from $d_1$ to $d_2$ . Energy regime is decreasing. High energy transfer functions.

**PROCEDURES USED IN SEDIMENT TREND ANALYSIS:** Sediment Trend Analysis attempts to determine patterns of sediment transport, or sediment pathways, at any particular site through the particle-size analysis of a large number of sediment grab samples collected on a (mostly) uniformly spaced grid. Sample grid spacing must be close enough that it can be safely assumed that sediment transport could conceivably occur between adjacent sample locations. In practice, selection of a suitable sample spacing is based on previous experience taking into account: (a) the number of sedimentological environments likely to be affecting the area of interest, (b) the spatial scale at which sediment transport trends need to be resolved, and (c) geographic boundaries of the study area. Reducing number of samples and/or increasing the sample spacing may add greater uncertainty to the results.

Several techniques to carry out STA have been developed, a good summary of which is found in Rios et al. (2003). The GeoSea approach is to use a vector analysis as an initial guide to

source-deposit relationships, followed by the one-dimensional, line-by-line approach whereby selected sample sequences are individually examined for statistically acceptable trends.

After the samples have been collected, and the grain-size distributions determined; a computer program is used to examine differences between the grain-size distribution parameters at each location relative to all neighboring sample locations. The goal of the computer program is to recognize statistically significant trends fulfilling the criteria listed in Table 1 for Cases B and C. In order to infer the direction of sediment transport at a given location,  $d_*$ , a minimum of eight additional samples are needed arranged in a 3x3 matrix with sample  $d_*$  located in the center of the matrix. From this matrix a statistical score is calculated for use in establishing sediment pathways. This process continues throughout the entire sampled regime. The minimum number of samples needed to estimate pathways is a 9x9 grid containing 81 samples.

The STA analysis steps are as follows:

- a. Assume the direction of sediment transport over an area containing many sample sites.
- b. From this initial assumption, predict the sediment trend that should appear along a particular sequence of samples.
- c. Compare the prediction with the actual trend that is derived from the selected samples.
- d. Modify the assumed transport direction and repeat the comparison until the best fit is achieved.

The important feature of this approach is the use of many sample sites to detect a transport direction. This helps reduce the uncertainty. The principal difficulty is that the number of possible pathways in a given area may be too large to automate the technique, or to test all possibilities. As a result, the choosing of trial transport directions has not been analytically codified. At present, the selection of trial directions is undertaken initially at random; although the term “random” is used loosely in that it is not strictly possible to remove the element of human decision-making entirely. For example, a first look at the possible transport pathways may encompass all north-south, or all east-west directions. As familiarity with the data increases, exploration for trends becomes less and less random. In other words, operator input can typically nudge the method toward a viable outcome. The number of trial trends becomes reduced to a manageable level through both experience and the use of additional information (usually the bathymetry and morphology of the area under study). When a final and coherent pattern of transport pathways is obtained that encompasses all, or nearly all of the samples, the assumption that the grain-size distributions are a result of sediment transport processes acting along the pathways has been verified, despite the inability to define accurately all the uncertainties that may be present.

Once sediment pathways have been established, the final step is computation and interpretation of what are termed “X-distributions” along the pathways. The X-distribution is defined mathematically as

$$X(s) = \sum_{i=1}^N \frac{[d_2(s)]_i}{[d_1(s)]_i} \quad (1)$$

This means for each sequential pair of deposits ( $d_1$  and  $d_2$ ) along the sediment pathway, the ratio of the grain-size distributions between deposits [ $d_2(s)/d_1(s)$ ] is calculated to provide a new distribution as a function of grain size. After this is completed for all sequential pairs, the composite X-distribution as a function of grain size is determined as the sum of all the individual distributions. Note that along the pathway, deposit  $d_2$  in one pair is often deposit  $d_1$  of an adjacent pair. Composite distributions composed of all the source deposits ( $d_1$ ) and destination deposits ( $d_2$ ) are also constructed in a similar manner, i.e.,

$$D_1(s) = \sum_{i=1}^N [d_1(s)]_i \quad \text{and} \quad D_2(s) = \sum_{i=1}^N [d_2(s)]_i \quad (2)$$

The  $X(s)$  distribution can be thought of as a function that describes the relative probability of each particle size being removed from deposit  $d_1$  and transported to deposit  $d_2$ . Based on the shape of the X-distribution along the sediment pathway relative to the shapes of the composite distributions  $D_1$  and  $D_2$ , McLaren and Bowles (1985) gave five scenarios for describing what is occurring along the pathway: (a) dynamic equilibrium, (b) net accretion, (c) net erosion, (d) total deposition I, and (e) total deposition II. These five cases are illustrated in Figure 1 and discussed as follows. (Important note: The abscissas on the plots in Figure 1 are in phi units, so finer grain sizes are to the right and coarser grain sizes are to the left.)

- a. **Dynamic equilibrium.** If the shape of  $X(s)$  resembles the  $D_1(s)$  and  $D_2(s)$  distributions (Figure 1a), the probability of a particular grain size being deposited is the same as the probability of that size being transported. So the bed is neither eroding nor accreting, but instead is in dynamic equilibrium.
- b. **Net accretion.** If the shapes of the three distributions are similar, but the mode of  $X(s)$  is skewed more toward the finer grain sizes (to the right in Figure 1b); net accretion is occurring. Because the modes of the deposits are coarser than  $X(s)$ , finer grained material is being transported and deposited, and this corresponds to Case B transport (fining sediments).
- c. **Net erosion.** If the shapes of the three distributions are similar, but the mode of  $X(s)$  is skewed more toward the coarser grain sizes (to the left in Figure 1c); net erosion is occurring. In this situation the coarser grain-sizes are being transported which corresponds to Case C transport (coarsening sediments).
- d. **Total deposition I.** If the  $X(s)$  distribution increases monotonically from coarse to fine grain sizes over the entire range as shown in Figure 1d, fine grains are being deposited along the sediment pathway (Case B) and not being remobilized. The shapes of the  $D_1(s)$  and  $D_2(s)$  distributions do not matter in this situation.
- e. **Total deposition II.** In extremely fine sediments (very fine silt or clay) the  $X(s)$  distribution may be nearly horizontal as shown in Figure 1e, indicating there is an equal probability of all grain sizes being deposited. This situation corresponds to sediments far from the source, and deducing sediment pathways based on changes in grain-size distribution becomes more problematic.

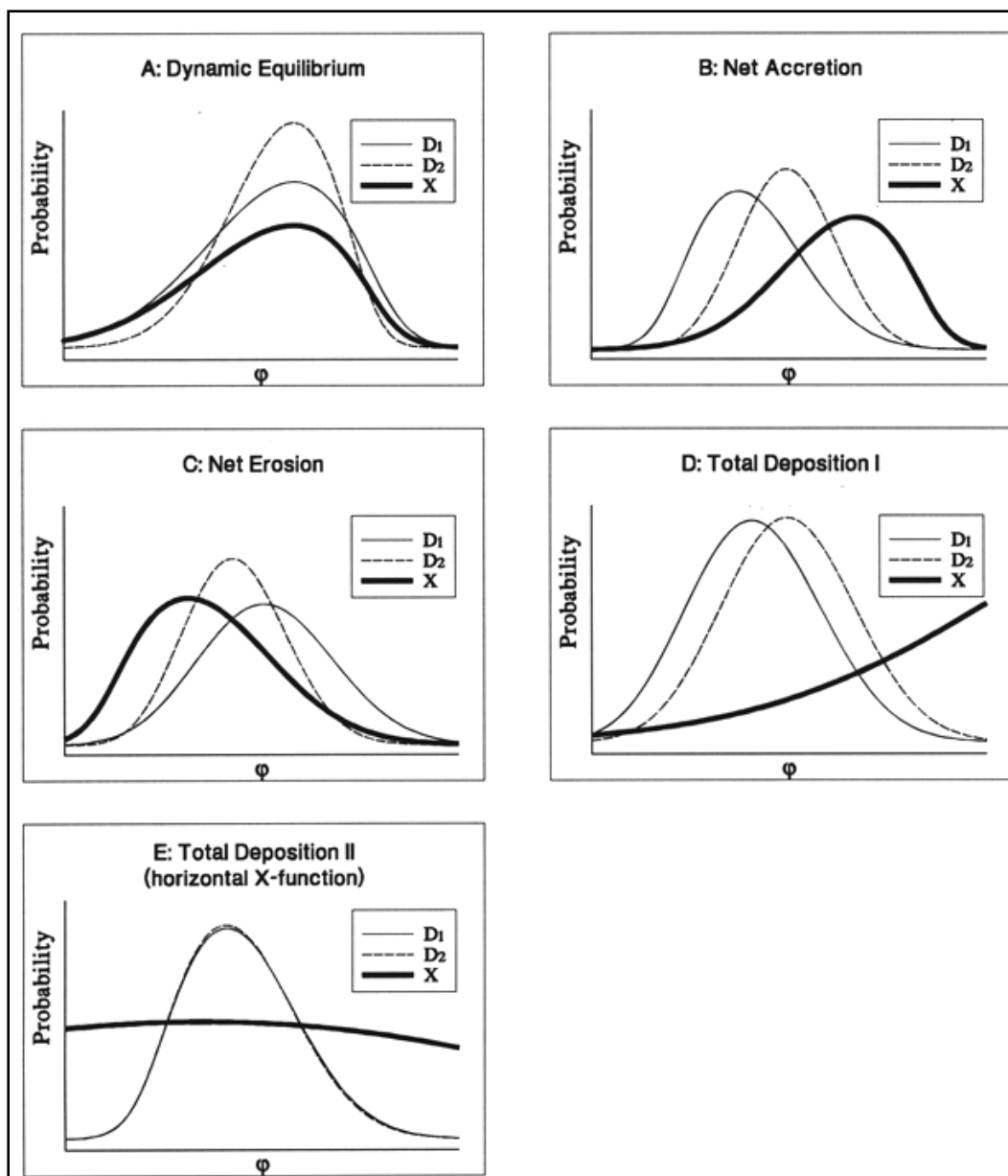


Figure 1. Interpretation of X-distribution along sediment pathways (Note: Abscissas on plots are in phi units so finer grain sizes are to the right and coarser grain sizes are to the left.)

The last step is representing the sediment pathways and perceived sediment transport process graphically by different colored arrows drawn on a map of the project area. As an example, Figure 2 shows results of STA obtained for San Juan Harbor, Puerto Rico (see location map, Figure 3). This study was completed in 2002 using 616 sediment samples. The green arrows indicate sand from the littoral system is being moved into the harbor where accretion occurs. Much of the inner harbor remains in dynamic equilibrium.

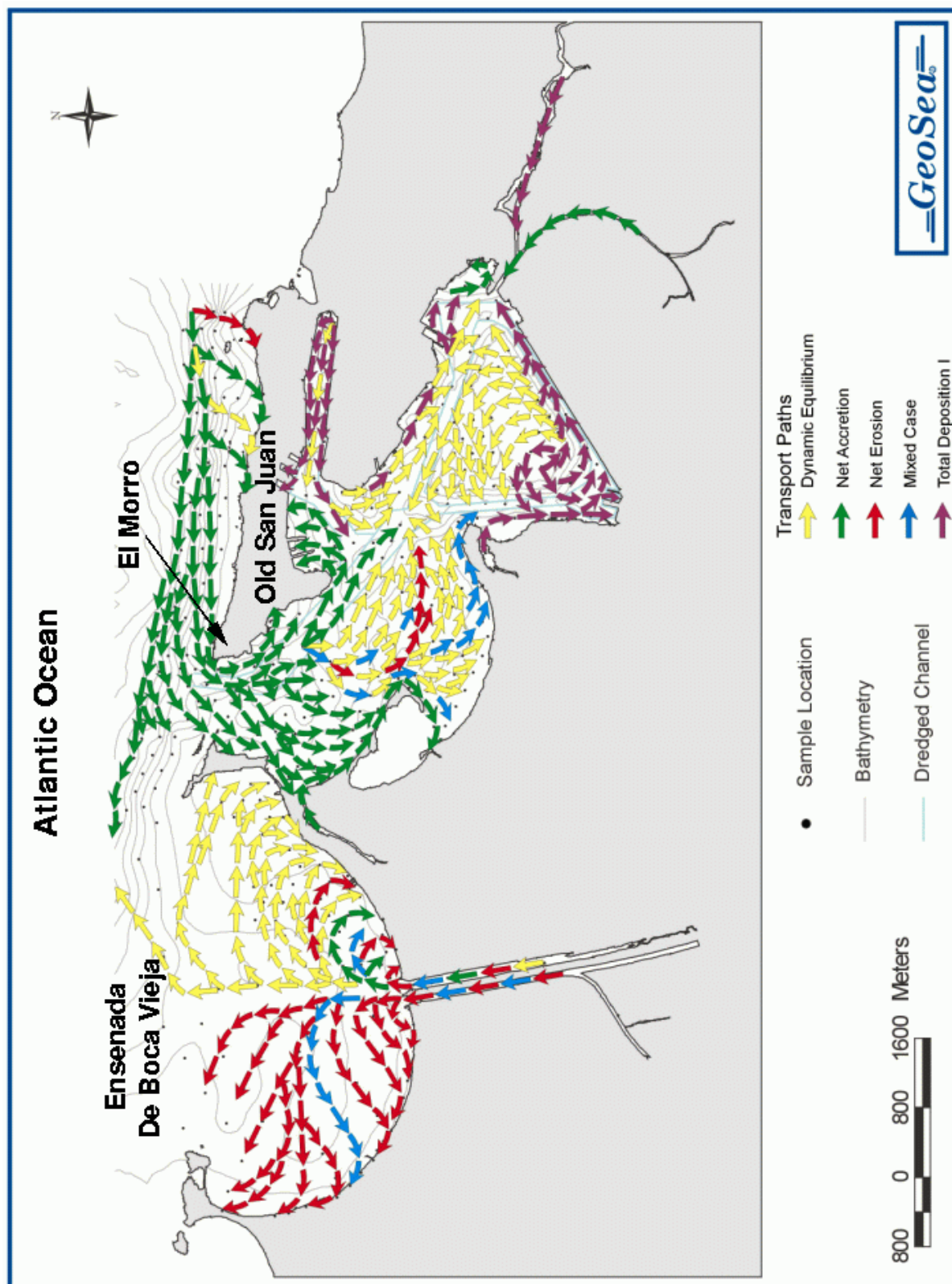


Figure 2. Sediment pathways for San Juan Harbor, Puerto Rico

Although the explanation of Sediment Trend Analysis is lacking in details, it attempts to give an overall impression of how the STA technique is applied. This information may be useful for evaluating the utility of STA for a particular project site.

**UNCERTAINTIES OF SEDIMENT TREND ANALYSIS:** Since its inception, many researchers have applied the concepts of STA to further their understanding of sedimentary environments. A number of authors found their results to agree, either in whole or in part, with a variety of other evidence including direct measurements of processes, observations of bed form orientations, and application of numerical modeling (Livingstone 1989; Lanckneus et al. 1992; Van de Kreeke and Robaczewska 1993; Gao and Collins 1994; Gao et al. 1994; Aldridge 1997; Bergemann et al. 1998; Van Der Wal 2000; Mallet et al. 2000; Duck et al. 2001; and Shi et al. 2002). The theory of STA was supported in independent research carried out by the U.S. Army Corps of Engineers (Teeter 1993; and Teeter et al. 2001). Nevertheless, some authors found no agreement between the STA (or various derivatives of the technique) and outside evidence (Flemming 1988; Masselink 1992; and Guillen and Jimenez 1995).

Voiced (but unpublished) criticism of STA methodology stems from specific project application of STA that yielded results different from what other coastal engineering experts believe is occurring in the nearshore sediment transport regime at that particular site. Whether or not the criticism is deserved depends on substantiating evidence for each specific application. It is always important to keep in mind that STA results must never be used without evaluating the result in the context of all other available information at the project site including hydrodynamics, known sediment transport trends, etc.

Initial development of STA sediment pathway maps such as illustrated in Figure 2 are based strictly on the sediment sample analyses without any consideration of known hydrodynamic conditions that could potentially influence sediment pathways. After the initial pathways are constructed based on statistical tests, knowledge of the local wave and current environment is examined to determine whether or not the derived sediment pathways make sense in terms of known hydrodynamic forcing. Of course actual construction of the sediment pathways is more involved than the simple description already given, and several additional factors must be considered before finalizing the sediment pathways.

Developers of the STA technique list several uncertainties associated with the methodology including the following:

- a. *Transport model assumptions.* The basic assumption of the transport model used in STA is that smaller grains are more easily transported than larger grains. Under this assumption, it can be shown that transport processes will change the moments of sediments in a predictable way. However, transfer functions obtained from flume experiments demonstrate this assumption is not strictly true. Factors such as shielding whereby the presence of larger grains may impede the transport of smaller grains, increasing cohesion of the finer grains, or the decreasing ability of the eroding process to carry additional fines with increasing load, demonstrate that the transport process is a complicated function related to the sediment distribution and the strength of the erosion process. Furthermore, this basic assumption implicitly dictates that the probability of transport of one particular grain size is independent of the transport of other grain sizes.

- b. *Temporal fluctuations.* Perhaps the most important uncertainty is that sediment pathways and patterns produced by STA are assumed to represent the integration of all physical processes responsible for transport and deposition of sediment at a given location over time. In a coastal regime this could include alongshore sediment movement driven by wave processes, onshore sediment movement during calmer wave climates, offshore sediment movement during storm periods, transport by ocean currents, and sediment carried by river flows and deposited from the sediment plume in the nearshore region. In other words, sediment samples may comprise the effects of several transport processes. It is assumed that what is sampled is the average of all the transport processes affecting the sample site. The average transport process may not conform to the transport model developed for a single transport process. The possibility also exists that different samples may result from a different suite of transport events. The temporal period for individual physical processes responsible for sediment deposition may vary from several tidal cycles, through the length of a storm season, to several years or more. The STA method cannot distinguish the time associated with the various processes, so while the result might indicate net erosion or deposition, the time scale (rate of erosion or deposition) cannot be determined. In STA, it is assumed that a sample provides a representation of a specific sediment transport type. There is no direct time connotation, nor does the depth to which the sample was taken contain any significance provided that the sample does, in fact, accurately represent the sediment transport type. For example, one sample may represent an accumulation over several tidal cycles, whereas another sample may represent several years of deposition. The trend analysis simply determines if there is a sediment transport relationship between the two sediment types.
- c. *Sample spacing.* Spacing of the sediment sampling grid must be close enough to assure adjacent samples are likely to be related by transport regime. With increased spacing there is increasing possibility that sediment samples are unrelated by transport mechanism. This could lead to false conclusions about the pathways between samples. Decreasing sample spacing increases the likelihood of adjacent samples being related by transport mechanism, but cost also increases. In practice, determination of an appropriate sampling grid for a specific site will be based on the number of different types of sediment environments thought to be present, e.g., beach sand, river silt deposits, etc.; the desired spatial scale of the sediment trends; and the geographical shape and extent of the study area.
- d. *Sediment size distribution.* Use of the log-normal distribution to characterize the sediment samples may introduce bias in the mean, variance, and skewness which are the key parameters on which the method is based. Other distributions have been proposed and debated in the literature (e.g., Hill and McLaren 2001; Hartmann and Flemming 2002).
- e. *Random environmental and measurement uncertainties.* All samples will be affected by random errors. These may include unpredictable fluctuations in the depositional environment, the effects of sampling and subsampling a representative sediment population, and random measurement errors.

In view of the these listed uncertainties, it is critical that results from any Sediment Trend Analysis be considered tentative until independent observations or analysis of known sediment erosion and deposition trends from the specific study site confirm the general pathways produced by STA.

Usually, a preliminary analysis of likely hydrodynamic forcing supporting the derived pathways is included as part of the STA product, but engineers more versed with the local hydrodynamic processes may have a different interpretation based on their knowledge and observation over many years.

The bottom line is that Sediment Trend Analysis is one interpretation of the sediment transport regime based on the assumption that sediment transport along a pathway results in modification of the grain-size distribution between adjacent sediment samples. The derived patterns of transport are, in effect, an integration of all processes responsible for the transport and deposition of the bottom sediments. To be valid, the STA pathways must generally conform to logical assessments based on past understanding and evidence of the sediment transport regime. In cases where there is substantial variance between the STA result and local knowledge of the transport regime, it is wise to re-examine the basis for the local knowledge before rejecting the STA results.

**BENEFITS OF SEDIMENT TREND ANALYSIS:** For locations where the sediment pathways are not well understood, STA may provide a tool for better understanding why certain erosion and deposition patterns have occurred. In the best case scenario, the derived pathways will conform to preexisting hypotheses and provide additional detail that can aid in development of engineering solutions to sedimentation problems. In the worst case, the STA results may stimulate debate and reveal what additional site measurements are needed to resolve any conflicts and promote better understanding of the sediment transport regime. The STA results must always be assessed in the context of what is already known at the site. Because STA cannot provide rates of sediment transport, erosion, or deposition, the findings may aid in directing the appropriate inputs into numerical modeling for further quantitative analysis.

STA does not give sediment pathways associated with single, extreme events unless the sampling is conducted soon after the event occurs, and it can be safely assumed that all collected samples are a direct result of the extreme event. Other methodologies such as numerical and physical models, or site measurements must be used to characterize sediment pathways during severe storms. However, if long-term average trends in sediment erosion and deposition are useful for project development, an STA study has potential benefit in adding to the understanding of the physical regime, potentially avoiding future problems, and perhaps reducing maintenance dredging.

Costs for conducting an STA study are directly related to the number of sediment samples required to cover the study area. Generally, STA studies cost less than comparable sediment tracer studies (which effectively only characterize the sediment pathways over the relatively short duration of the tracer experiment). STA will also be less expensive than most field measurement programs utilizing a suite of sensors, but on the other hand STA does not provide information on transport rates that could be determined from a field measurement program.

The end products from STA include a map delineating the main sediment transport environments within the study area and a map indicating both the sediment pathways and the regions of net erosion, net accretion, dynamic equilibrium, total deposition, and mixed regimes. These are useful for understanding where sediment is moving within the sampled region, and the maps can serve as a predictive tool for initial assessment of what might occur if engineering modifications are made at a project site. However, recall that the STA methodology represents integration over time of all processes acting at a location. So it would not be appropriate to base a prediction of the response of a

project to an engineering modification solely on the results of the STA. Other understanding about the site in particular and typical response of the engineering modification in general must be taken into consideration.

STA can be applied to a wide range of sediment types ranging from clay-sized cohesive materials all the way up to gravel deposits. Because the methodology makes no assumptions about the sediment transport mechanisms other than fine grains are more likely to be transported than coarser grains, it can be applied to nearly all hydraulic environments including riverine, estuarine, coastal, and mixed regimes. Finally, the large number of samples (and analyzed distributions) required to perform STA may be useful as numerical modeling input, remote sensing ground truth (e.g., acoustic mapping, sidescan sonar), habitat studies, and baseline data for documenting future changes in the sediment regime.

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## EXAMPLE APPLICATION: AGUADILLA HARBOR, PUERTO RICO

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Figure 3. Aguadilla Harbor project location map

**BACKGROUND:** In 1995 the U.S. Army Corps of Engineers constructed a small breakwater as part of a harbor project at Aguadilla, Puerto Rico (Figure 3). Figure 4 shows an oblique aerial view of the harbor project in 1998. Since the breakwater construction, the harbor has suffered from shoaling by littoral sediment moving through the more porous sections of the breakwater and around the southern tip of the structure (Figure 5). The harbor project was monitored under the Monitoring Completed Navigation Projects (MCNP) Program conducted by the U.S. Army Engineer Research and Development Center (ERDC). One aspect of the monitoring program was to investigate the physical mechanisms that result in harbor shoaling and to determine the local sediment pathways and the source of sediment that reaches the harbor. A Sediment Trend Analysis study was funded to address this question.



Figure 4. Aerial view of Aguadilla Harbor, Puerto Rico (September 1998)



Figure 5. Shoaling of Aguadilla Harbor as viewed from top of parking garage (May 2002)

**SEDIMENT TREND ANALYSIS SAMPLING PLAN:** Sampling plans for STA studies are determined by study requirements and the nature of the environment. For the relatively small coastal region delineated for the Aguadilla Harbor study, a total of 269 samples were specified as denoted by the circular dots in Figure 6. In the immediate vicinity of the breakwater grid, spacing was 75 m (246 ft). Farther away from the harbor to the north and south grid, spacing was increased to 150 m (492 ft) to establish possible relationships of sediment sources on a more regional scale. During sampling, hard bottom was encountered at 23 locations, so the final number of collected sediment samples was 246. The majority of collected samples (84.2 percent) were classified as sand, followed by muddy sand (12.2 percent) and sandy mud (3.6 percent).

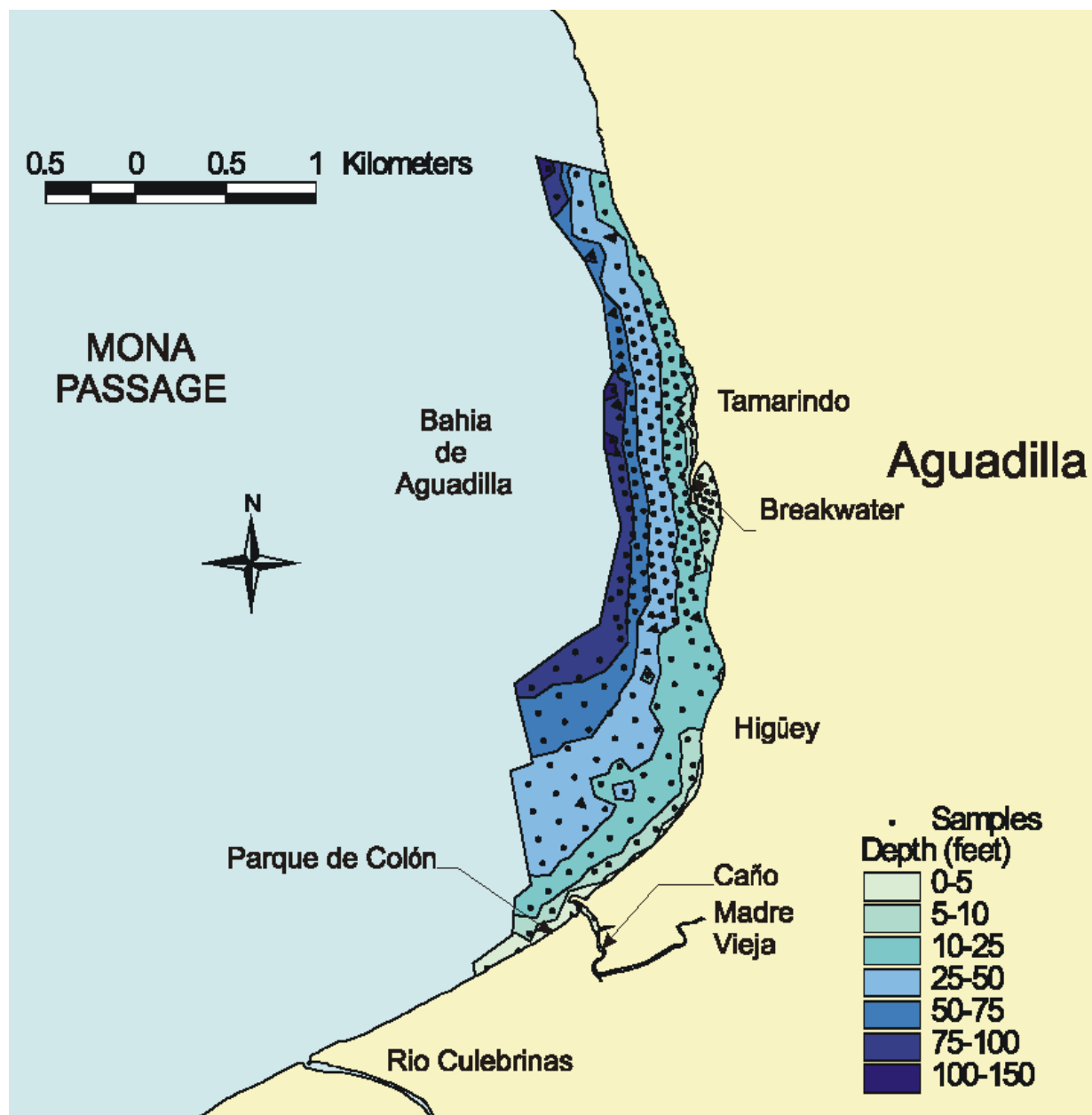


Figure 6. Sediment sampling grid for Aguadilla Harbor Sediment Trend Analysis

**SEDIMENT TREND ANALYSIS RESULT:** The major result from the STA of the 246 sediment samples was a map of 51 derived sediment pathways shown in Figure 7. The sampled region exhibited two major transport regimes. The first regime (TE1) extended from the northern limit of the study area to about 500 m (1,640 ft) south of the breakwater tip (a location that marks the northern boundary of a hard-ground bottom feature). The STA indicated that TE1 was about 51 percent accretional and 40 percent mixed erosion/accretion. At the offshore limit of TE1 sediment moves in a southerly direction and generally onshore from deeper water. Nearshore there were indications of transport in a northerly direction with pathways entering the harbor through the entrance. Of particular note is the absence of accretional sediment pathways moving farther south of the harbor into the historically eroding region to the south.

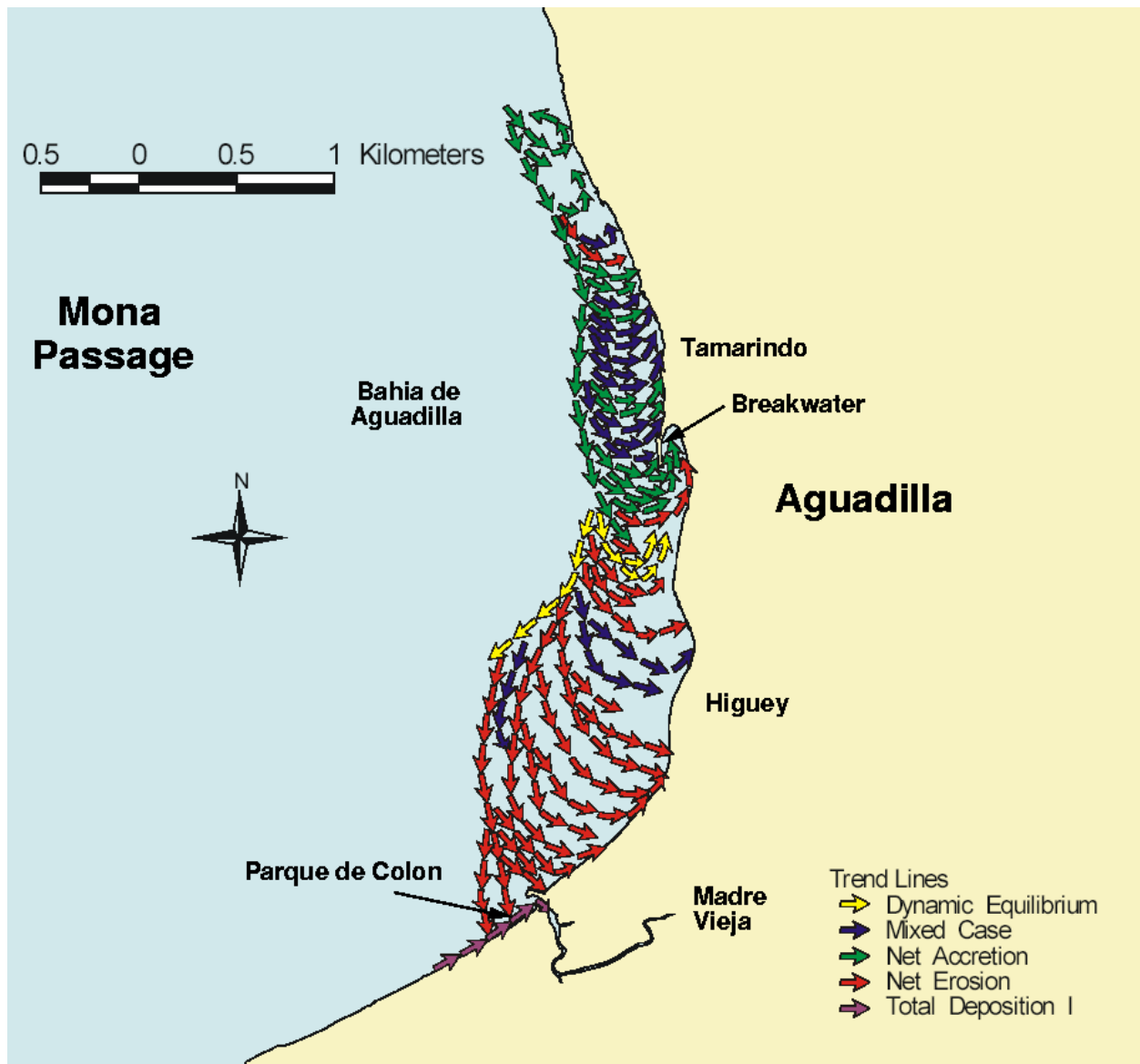


Figure 7. Sediment pathways and transport regimes for Aguadilla Harbor study

The second identified transport regime (TE2) extends from about 500 m (1,640 ft) south of the harbor to the southern limit of the study area. Within TE2 the trend is predominately erosional (73 percent) with some mixed erosion/accretion (27 percent). The shoreward directed erosional arrows in Figure 7 are somewhat misleading, and the explanation is that these pathways are balanced by seaward transport of sediment by suspension during storm events.

The two important results of the STA for the Aguadilla Harbor monitoring study include the following:

- a.* Sand transported from the offshore region appears to be the source of sand shoaling the Aguadilla Harbor. This result is in agreement with the observation that southward-directed longshore transport at Aguadilla is quite small, and thus, was not likely to be the main contributor to harbor shoaling.
- b.* The pathways indicated the sediment-deprived region south of the harbor receives little sediment from the north or from offshore. Thus, the trapping of sediment by the harbor is not contributing to the lack of littoral sediment evident farther south of the harbor. This conclusion is supported by the knowledge that the shoreline in TE2 was deprived of sediment before harbor construction in 1995.

**INTERPRETATION OF HYDRODYNAMIC FORCING:** Before accepting the results of a Sediment Trend Analysis, it is imperative that the derived sediment pathways and sedimentation trends can be explained in terms of hydrodynamic forcing. Only then can greater credence be given to the STA result. As part of the analysis for Aguadilla, the contractor examined published literature to gain a better understanding of which physical processes were thought to have relevance for forcing sediment transport.

The study's authors suggested that the primary sediment transport forcing comes from strong southward ocean currents moving through the Mona Passage along the west coast of Puerto Rico. These currents are thought to generate a countercurrent consisting of a shoreward directed flow and a northward return flow close to the shoreline. The primary source for sand deposited offshore of Aguadilla is most likely remnants of littoral transport moving westward along the north coast of Puerto Rico and swept southward by the Mona Passage current (although much of the material is lost to deeper water). Thus, it was concluded that the primary forcing mechanism for sediment transport at Aguadilla is oceanic currents rather than wave-induced longshore transport.

Strong currents in the Mona Passage are not thought to be driven by the local wave climate; so according to the STA, sediment deposition in the Aguadilla Harbor should be an ongoing process even during periods of calm waves. Bottin (2001) stated that harbor shoaling occurred during limited wave action, and this supports the STA conclusions. However, observations have also shown that the harbor shoals rapidly during storms; and a dye study by Hughes (2002) during a moderate storm indicated significant quantities of nearshore sand were being mobilized and driven into the harbor around the south tip of the breakwater. Hughes's study was unable to identify the source of the shoaling sand other than the fact the sand was available in the nearshore just offshore of the breakwater.

In summary, the Sediment Trend Analysis performed for Aguadilla, Puerto Rico, identified sediment pathways and erosion/depositional trends that are consistent with observed gross trends at the project site. Earlier observations had tended to rule out southward longshore transport as the source for harbor shoaling material, leaving only onshore moving sediment as a viable source. However, sediment transport by strong nearshore countercurrents associated with the Mona Passage ocean current had not been considered to be the primary forcing mechanism. The derived sediment pathways were consistent with this forcing hypothesis, but field measurements are needed to confirm the existence of currents capable of moving sediment along the prescribed pathways. The STA provided a better understanding of the source and movement of sediment in the Aguadilla Harbor project region. Because the STA conformed to established gross sediment transport trends and could be explained in terms of plausible hydrodynamic forcing, more credence can be given to the result. Had the result not conformed to existing knowledge, the STA would have been viewed in a less favorable light. Nevertheless, confirmation of the countercurrent magnitudes with field measurements would have added strength to the STA conclusions.

**ADDITIONAL SITE-SPECIFIC STA APPLICATIONS:** Table 2 lists STA applications completed by Corps Districts as of the year 2004. The contractor supplied final written reports, figures, and analyses; but none of the STA studies have been published as Corps reports available to the public. Questions about specific studies should be addressed to the Corps Districts listed in the table.

<b>Table 2 Sediment Trend Analyses Performed for Corps Districts</b>			
<b>Project Site</b>	<b>Corps District</b>	<b>Number of Samples</b>	<b>Year of Study</b>
Sediment transport pathways and dispersal of dredged material in Mississippi River, mile 26.5 to mile 29.5	St. Louis District	260	1992
Sediment transport in Elliott Bay and Duwamish River, Seattle: Implications to estuarine management	Seattle District (as part of the State of Washington: Department of Ecology: Toxics Cleanup Program)	568	1994
Sediment trend analysis (STA) of Anacostia River	Baltimore District (as part of AWTa – Anacostia Watershed Toxics Alliance)	602	2000
Sediment trend analysis (STA) and Acoustic Bottom Classification (ABC) in mouth of Columbia River: Implications to dredge disposal operations and coastal erosion	Portland District	1252	2001
Sediment trend analysis in San Juan Harbor and vicinity, Puerto Rico	Jacksonville District	616	2002
Sediment trend analysis in the vicinity of Aguadilla Breakwater, Puerto Rico	Jacksonville District	269	2003
Sediment trend analysis in Maumee Bay, Lake Erie	Buffalo District	930	2003

**SUMMARY:** This CHETN has described the Sediment Trend Analysis (STA<sup>®</sup>) for estimating net sediment pathways in coastal and estuarine environments. The STA technique is based on analyses of sediment samples collected over a uniform grid in the region of interest, and it provides maps indicating sediment pathways, erosion and accretion areas, and areas that are in dynamic equilibrium. Results of an STA study for Aguadilla Harbor, Puerto Rico, were provided as an example application.

Like any analysis of nearshore sediment transport processes, the STA results must be considered in conjunction with other knowledge about the study area trends and hydrodynamic forcing. This helps to assure the results are logical, defensible, and consistent with known facts. In other words, STA results that are contrary to accepted notions of local sediment transport processes must be logically explained and perhaps even verified with subsequent field measurements. Fortunately, the STA usually reveals what field measurements are needed to either prove or refute the analysis.

**POINTS OF CONTACT:** This CHETN is a product of the Aguadilla Harbor, Puerto Rico, Monitoring Work Unit of the Monitoring Completed Navigation Projects (MCNP) Program being conducted at the U.S. Army Engineer Research and Development Center (ERDC), Coastal and Hydraulics Laboratory (CHL). Questions about this technical note can be addressed to Dr. Steven A. Hughes (Voice: 601-634-2026, Fax: 601-634-3433, e-mail: [Steven.A.Hughes@erdc.usace.army.mil](mailto:Steven.A.Hughes@erdc.usace.army.mil)) of ERDC, CHL. For information about the MCNP Program, please contact the MCNP Program Manager, Dr. Lyndell Hales at [Lyndell.Z.Hales@erdc.usace.army.mil](mailto:Lyndell.Z.Hales@erdc.usace.army.mil). Beneficial reviews were provided by Mr. Thomas Smith, U.S. Army Engineer District, Honolulu; and Dr. Patrick McLaren, GeoSea, Consulting, Ltd.

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